GROWTH AND CHARACTERIZATION OF RADIATION INDUCED MIXED TARTRATE SINGLE CRYSTALS

Synopsis submitted to fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

PHYSICS

by

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Title of the Thesis	:	Growth and characterization of radiation induced mixed tartrate single crystals
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Introduction

The growth and characterization of crystalline materials are an enormously important and productive branch of research. The many crystal growth techniques increasingly being used for the crystallization of organic, inorganic, organometallic compounds, and biological macromolecules [1-3]. Organometallic crystals may be thought as a relation between organic molecular crystals and inorganic solids or bulk metals. The electronic structure of the metals and the patterns of intermolecular interactions formed by the ligands affect the properties of certain solid organometallic materials. Carboxylic acids, which are important building blocks for many life molecules, can serve as an important ligand in the formation of organometallic materials [4-5]. An analysis of the literature indicates research on crystal growth of certain metal carboxylates such as tartrate, malate, oxalate, and so on.

Many researchers have published articles on the synthesis of metal tartrate using conventional methods, but less consideration has been devoted to radiation induced growth of metal tartrate single crystals [6-7]. As a result, this study, titled "Growth and characterization of radiation-induced mixed tartrate single crystals" examines the growth, characterization, and properties of radiation induced mixed tartrate single crystals. Also, the comparison of irradiated and non-irradiated crystals provides a new perspective on single crystal growth.

The insolubility of tartrate in water is an advantage when silica gel methods are used to grow these crystals. Since the silica gel is viscous in nature, simulates biological fluids, it can be used to produce crystals of biologically significant molecules at room temperature[8-9].The gel method will create crystals with high optical perfection and complex morphology. It is a simple, elegant, and room temperature growth process that is suitable for developing various single crystals and hence has invited countless researchers to use the gel method to produce single crystals [10-12]. However, literature surveys indicates that the crystallization by inducing radiation on the growth phase of mixed tartrate can only be recorded on a small number of reports. This has contributed to an intent to use the irradiation process to create more tartrate crystals.

Aims and objectives

The researcher aims to carry out a systematic experimental study on growth and characterization of different light radiated single crystals by using hydro silica gel as the growth medium and to explore their thermal, optical, electrical and magnetic properties by analysing them with the help of the conventional characterization techniques. The characterization of the crystals

is a major part of this work, which helps to learn more about the mechanism and properties of these crystals.

The objectives of the present work are:

- Growth of radiation-induced mixed tartrate single crystal by single diffusion gel growth technique.
- Investigation of effect of radiation on crystal growth and morphology.
- Study of Fourier transform infrared for the multiple bonding modes and the functional groups of grown crystals (FT-IR).
- Structural characterization of irradiated and non-irradiated gel grown single crystals using single crystal X-ray diffraction (XRD) and powder X-ray diffraction studies.
- UV-Vis-NIR spectrophotometer determines the band gap energy of crystals.
- Studies on thermal decomposition behavior of the crystals by thermogravimetric (TG) analysis, differential thermal analysis (DTA), and differential scanning calorimetry (DSC).
- Determination of dielectric behaviour of the grown crystals.

Organization of the thesis

The thesis titled "Growth and characterization of radiation induced mixed tartrate single crystals" is divided into seven chapters.

Chapter 1: Introduction

The chapter 1 gives the importance of crystals, their applications and growth by gel technique. Various crystal growth and crystal growing methods and their classifications were discussed. This chapter explains the classification of crystals, structure, crystal system, method of growth. The various growth method namely; Growth from solid, vapour, melt, and solution were explained. The growth from solution classified into four types are High-temperature solution growth, Low-temperature solution growth, hydrothermal growth, Gel growth methods. The principle of gel growth and its mechanism, various types of gel, the structure and properties of silica gel were explained. A detailed report about the growth mechanism, nucleation control in gel growth, and also the advantages of gel techniques was given. The aims and objectives of the research work are mentioned in this chapter.

Chapter 2: Experimental Methods

This chapter provides the different types of the crystallization process in gel medium namely; chemical reaction method, complex dilution method, chemical reduction method, and solubility reduction methods were explained. The experimental details of the growth process of mixed tartrate single crystals using single diffusion gel technique and the effect of different growth parameters such as pH of the gel, concentration of supernatant solutions, specific gravity ($g.cm^{-3}$)

on growth and the experimental procedure for the preparation of different types of crystals are also included in this chapter. The experimental details of the growth process of irradiated and non-irradiated mixed tartrate single crystals using single diffusion gel technique and the effect of various radiations (Laser, Ultraviolet, CFL, and LED) on the growth are explained in detail in chapter.

Also the methodologies used in the growth and characterization of single crystals. This chapter describes the principles and involvement of various instruments. Energy dispersive X-ray (EDX), Field emission scanning electron microscope (FESEM), Fourier transform infrared (FT-IR) spectrophotometer, Thermal analyzer (TGA/DTA/DSC), Magnetic susceptibility measuring instrument (Gouy balance), UV-Vis-NIR spectrophotometer, Powder X-ray diffractometer (PXRD).

We developed 4 series of crystals namely: Cadmium mixed copper tartrate (CdCuT), Cobalt mixed copper tartrate (CoCuT), Magnesium mixed copper tartrate (MgCuT), and Manganese mixed copper tartrate (MnCuT) crystals with irradiated 4 type of light irradiation were discussed in chapter -3, 4, 5, and 6.

Chapter 3:

Growth and characterization of radiation induced cadmium mixed copper tartrate (CdCuT) single crystals

Review of literature on growth of single crystals by gel techniques reveals various parameters (density of SMS, temperature, concentration of reactants, radiations) will strongly change the size, morphology and other characteristics of the crystals. As such effect of radiation may also play an important role not only on growth but also on various physical and chemical properties of the crystals particularly for tartrate crystals. Based on this idea the researcher has started the work on growing the tartrate single crystals by inducing the radiations of different types (different wavelength) at the time of growing crystals in test tubes by gel techniques. Various types of radiation induced are listed below.

Sl. No.	Types of radiation	Wavelength(nm)	Luminous flux(lumen)
1.	Ultraviolet	280-315	900
2.	Laser	635	0.905
3.	CFL	400-700	550
4.	LED	432	800

The above radiations are induced directly on the experimental test tubes containing the cation mixtures for a period of 25 to 30 days continuously.

Single crystals of cadmium mixed copper tartrate single crystal were grown by single diffusion method in silica hydro gel at different light radiation. Optimum conditions of the as grown crystals were established by varying Specific gravity of Sodium Meta Silicate (SMS), gel setting time, pH of the gel, concentrations of tartaric acid and concentration of Cd^{2+} and Cu^{2+} solutions. Energy dispersive X-ray analysis (EDX) confirmed the presence of Cd, Cu, O, and C present in the CdCT single crystals. The tables confirm cationic distribution of without irradiation **(Cu^{2+}: Cd^{2+}:36.12: 1)**, UV is **(Cu^{2+}: Cd^{2+}:13.19:1)**, laser **(Cu^{2+}: Cd^{2+}:13.98:1)**, CFL **(Cu^{2+}: Cd^{2+}:16.21:1)**, and LED **(Cu^{2+}: Cd^{2+}:20.82:1)**. The FESEM images of an enlarged 20µm with 500X surface morphology of the grown CdCT single crystals. The FESEM images confirms the effect of crystal morphology of irradiation and non-irradiation. Fourier transform infrared (FT-IR) spectrum exhibits the presence of OH, carboxyl group and metal-oxygen bonding. The FT-IR spectra of the irradiated spectrum compared with the non-irradiated spectrum, clearly show the shifting of the band due to chain scission over cross-linkages in the irradiation effect. UV-Visible spectroscopic analysis measured the energy gap and insulating behavior of the crystals. Thermal decomposition pattern of the different irradiated and non-irradiated CdCT single crystals is shown in Figures. Their weight was lost continuously based on the temperature applied. It was clearly shown that the overall decomposition divided into two consecutive steps described as follows. At the first stage, the crystal loses water and becomes anhydrous in the temperature range between 25 to 120^{o} C. These results clearly show the formation of anhydrous cadmium copper tartrate. At the second stage between 190 – 320^{o}C, by the loss of carbon monoxide and carbon dioxide, the anhydrous cadmium copper tartrate was converted into oxide form. This clearly shows the formation of cadmium copper oxide. The irradiated and non-irradiated CdCT single crystals of observed weight loss percentage, calculated weight loss percentages, and the decomposition of the molecules of the crystal were tabulated .The figures and table clearly show the effect of temperature on the grown irradiated and non-irradiated CdCT single crystals. In a DTA curve of semiconductor laser irradiated CdCT single crystals at 97.17 °C endothermic peak was observed due to loss of water of crystallization. Loss of weight at temperature range 90 to 110 °C relates to the loss of water of crystallization. Which is an endothermic character. The exothermic peak observes at 263.20 °C shows the decomposition of tartrate. Loss of weight at the temperature relates to the release of CO and CO_2 respectively and which are exothermic. In semiconductor laser irradiated DSC curves the 90 °C is the initial temperature and 110 °C equilibrium temperature. The initial phase change starts at 90 °C and a peak of temperature 97.78 °C change in phase is completed which is endo-down. In another curve shows the initial temperature 210 °C and 220 °C equilibrium temperature. The final phase change starts at 210 °C and ends at 263.20 °C. The initial and final phase of the DSC curve and the calculated area and change in enthalpy are shown in Table. The dielectric constant is found to be high in the lower frequency area for all temperatures and subsequently falls with increasing frequency up to 40 Hz. The CdCT dielectric

loss behavior at high frequency suggests that the improved optical quality with fewer flaws. In the CdCT crystals, SLR ($\varepsilon_r - 93.54$) has the highest dielectric constant, and LED ($\varepsilon_r - 29.79$)is a low dielectric constant. The remaining are observed in CFL ($\varepsilon_r - 78.11$), UV ($\varepsilon_r - 36.02$), and non-irradiation ($\varepsilon_r - 38.94$) at the higher frequency range (40 Hz-1 MHz). The dielectric loss of various irradiated CdCT crystals is UV (tanδ-4.07), LASER (tanδ-3.35), CFL (tanδ-2.13), LED (tanδ-2.63), and non-irradiation (tanδ-2.35) respectively at 40 Hz. I-V characterization of Laser irradiation crystals' current gives a high conductivity and UV irradiate crystals give low conductivity. Irradiation crystals give less conductivity, like UV (I_{max}-0.4872×10^{-6} A), LED (I_{max}-1.39×10^{-6} A), CFL (I_{max}-1.24×10^{-6} A), and Laser (I_{max}-11×10^{-6} A) irradiation gives more conductivity compared to the other irradiation and non-irradiation (I_{max}-11×10^{-6} A). The crystallographic parameters position 2θ, intensity, and d spacing value are used to identify the crystal geometry and space group. The calculated data was compared with the standard JCPDS data (Card Number: 01-0158). . The lattice parameter and unit cell parameter of the produced crystals, which is a monoclinic system with a ≠ b ≠ c and α = γ=90˚ but β ≠ 90˚.

Chapter-4:

Growth and characterization of radiation induced cobalt mixed copper tartrate (CoCuT) single crystals

Single crystals of cobalt mixed copper tartrate single crystal were grown by single diffusion method in silica hydro gel at different light radiation. Optimum conditions of the as grown crystals were established by varying Specific gravity of Sodium Meta Silicate (SMS), gel setting time, pH of the gel, concentrations of tartaric acid and concentration of Co^{2+} and Cu^{2+} solutions. Energy dispersive X-ray analysis (EDX) confirmed the presence of Co, Cu, O, and C present in the CoCuT single crystals. The FESEM confirms the crystal morphology of the grown crystals. Fourier transform infrared (FT-IR) spectrum exhibits the presence of OH, carboxyl group and metal-oxygen bonding. The FT-IR spectra of the irradiated spectrum compared with the non-irradiated spectrum, clearly show the shifting of the band due to chain scission over cross-linkages in the irradiation effect. UV-Visible spectroscopic analysis measured the energy gap and insulating behaviour of the crystals. TGA, DTA, and DSC confirms the thermal behaviour and decomposition of the molecule of the grown CoCuT crystals. The dielectric constant and dielectric loss of the crystals were studied at constant temperatures using Agilent 4294A impedance analyser. The crystallographic parameters position 2θ, intensity, and d spacing value are used to identify the crystal geometry and space group. The calculated data was compared with the standard JCPDS data (Card Number: 01-0158). . The lattice parameter and unit cell parameter of the produced crystals, which is a monoclinic system with a ≠ b ≠ c and α = γ=90˚ but β ≠ 90˚.

Chapter-5:

Growth and characterization of radiation induced Magnesium mixed copper tartrate (MgCuT) single crystals

Single crystals of Magnesium mixed with copper tartrate were grown in silica hydrogel using a single diffusion method at various light intensities. Optimal conditions for the as-grown crystals were established by varying the specific gravity of sodium metasilicate (SMS), gel setting time, pH of the gel, concentrations of tartaric acid, and concentrations of Mg^{2+} and Cu^{2+} solutions. Energy dispersive X-ray analysis (EDX) confirmed the presence of Mg, Cu, O, and C in the MgCuT single crystals. The crystal shape of the produced crystals is confirmed by the FESEM. A carboxyl group called OH as well as metal-oxygen bonding may be seen in the Fourier transform infrared (FT-IR) spectrum. The shifting of the band caused by chain scission across cross-linkages in the irradiation effect is seen in the analysis of the FT-IR spectra of the irradiated and non-irradiated spectrums. The energy gap and insulating characteristics of the crystals were assessed by the UV-visible spectroscopic examination. The temperature behaviour and molecular breakdown of the generated MgCuT crystals are confirmed by TGA, DTA, and DSC. The crystals' dielectric loss and dielectric constant were investigated. Position 2θ, intensity, and d spacing values of the crystallographic parameter are utilized to specify the crystal shape and space group. Comparing the expected data to the standard JCPDS data (Card Number: 01-0158). The lattice parameter and unit cell parameter of the produced crystals, which is a monoclinic system with $a \neq b \neq c$ and $\alpha = \gamma = 90^{\circ}$ but $\beta \neq 90^{\circ}$.

Chapter-6:

Growth and characterization of radiation induced Manganese mixed copper tartrate (MnCuT) single crystals

A single diffusion technique was used to generate single crystals of manganese and copper tartrate in silica hydrogel under varying light intensities. By adjusting the sodium metasilicate's (SMS) specific gravity, gel setting time, gel pH, tartaric acid concentrations, and concentrations of Mn^{2+} and Cu^{2+} solutions, the ideal crystal growth conditions were found. Mn, Cu, O, and C were identified by energy dispersive X-ray analysis (EDX) in the MnCuT single.The crystal shape of the produced crystals is confirmed by FESEM. The presence of O-H, a carboxyl group, and metal-oxygen bonding may be seen in the Fourier transform infrared (FT-IR) spectrum. When comparing the FT-IR spectra of the irradiated and non-irradiated spectrums, it is evident that the irradiation effect's chain scission across cross-linkages caused the band to move. The crystals energy gap and insulating properties were determined by UV-visible spectroscopic examination. The thermal behaviour and molecular decomposition of the MnCuT crystals are confirmed by TGA, DTA, and DSC. A electrical properties study was done on the crystals dielectric loss and dielectric constant.

To determine the crystal shape and space group, the values of the crystallographic parameters at positions 2θ, intensity, and d are employed. Comparisons between the computed data and standard JCPDS data (Card Number: 01-0158). The lattice parameter and unit cell parameter of the produced crystals, which is a monoclinic system with $a \neq b \neq c$ and $\alpha = \gamma = 90^{\circ}$ but $\beta \neq 90^{\circ}$.

Chapter 7: Summary and scopes for future study

Chapter 7 reveals the summary of the research work in brief. The experiments were carried out under constant optimized conditions. The growth process is carried out in single test tubes. During the growth nucleation sites were irradiated with Laser, Ultraviolet, LED and CFL. The irradiated and non-irradiated crystals grown by single diffusion gel technique by achieving optimization condition with specific gravity 1.045 $g.cm^{-3}$, gelling time 48 hours, 1 M concentration of 2 m*l* copper chloride solution, 0.5 M concentration of 2 m*l* (magnesium chloride, manganese chloride, cadmium chloride, cobalt chloride) solutions. The irradiation of light on growth phase results variation in various properties of the crystals. The variation in the elemental cationic distribution of irradiated and no-irradiated crystals in EDX results shows effect of light radiation on growth of these crystals. Thermal studies reveal that the grown crystals are stable at its oxide state above 300°C. Different functional groups (O-H, C-H, C=C, C-O, M-O) present in the grown crystals were identified using infrared spectrophotometer. Using the results of EDX, TGA, and FT-IR, the molecular formula and molecular weights of the grown crystals were estimated. Molecular weights of the crystals vary due to the irradiation of various light radiations. The band gap energy and optical constants were determined using absorption spectra. The band gap energy ($E_g > 4.5$ eV) varies due to the irradiation reveal the effect of light radiation on the growth phase. The existence of a high value of bandgap energy confirms the insulating behaviour of crystals. The higher value of electrical susceptibility ($\chi_e > 3$) suggests that the crystals are easily polarizable when light incident on them. Lower values of dielectric constant and dielectric loss at higher frequencies confirm the high optical quality with lesser defects of the grown crystals. This is the much needed specification for optoelectronic devices. The high value of leakage resistance (in MΩ) from the V-I characteristic study also supports the low conductivity (10^{-6} $S.m^{-1}$) of the crystals. The occurrences of negative weight change (Δw), gram susceptibility (10^{-6} e.m.u), molar susceptibility (10^{-6} e.m.u) of irradiated and non-irradiated crystals exhibit diamagnetic behaviour. The high intense peaks at various Bragg angle (2θ) from the powder X-ray diffractograms exhibit the high crystallinity of the sample. The computed values of crystal parameters confirm that all the grown twenty crystals belong to a monoclinic crystal system.

Recent experiments and results show it should be useful to other scientists in this field. Different types of crystals can be grown by the addition of different dopants to grow many shapes of extremely perfect single crystals. In future, varieties of dopants such as organic and inorganic

impurities can be added by gel method. Among the large number of grown crystals by gel method, properties of a few have been studied.

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Research publications:

1. **Publication related to the thesis:**

A. Published in journals

1. **K.V. Pradeepkumar**, P. S. Rohith, N. Jagannatha, Effect of semiconductor laser irradiation on growth and characterization of cadmium doped copper tartrate single crystals, ***J. Cryst. Growth,*** 2021, 563, 126107.
2. **K.V. Pradeepkumar**, P. S. Rohith, N Jagannatha Growth and Characterization Studies of MgCT Single Crystals in Silica Gel and Nucleation Reduction Strategy at Different Radiations, ***J. Mater. Environ. Sci.*** 2020, 11(8), 1294-1303.

3. **K.V.Pradeepkumar,** P.S. Rohith, N Jagannatha, "Growth, Characterization and Nucleation Reduction Mechanism of CCT Crystals in Silica Gel Medium at Different Environments" ***J. Appl. Chem.*** 2019, 8 (4), 1893-1899.

B. Published in conference proceedings

1. **K.V. PradeepKumar,** P.S. Rohith, N. Jagannatha, "Growth, optical and thermal properties on Co^{2+} doped copper tartrate single crystals and different environmental conditions", ***J. Phys. IOP Conf. Ser.***, 1495 (1), 012009.
2. **K.V. PradeepKumar**, P.S. Rohith, N. Jagannatha, "Effects of light radiation on spectral studies of gel grown Mg^{2+} doped copper tartrate single crystals" ***AIP Conf. Proc.,*** 2220, 060008 (2020).
3. **K.V. PradeepKumar**, P.S. Rohith, N. Jagannatha, "Effects of light radiation on spectral studies of gel grown Co^{2+} doped copper tartrate single crystals" ***AIP Conf. Proc.,*** 2244, 100003 (2020).
4. **K.V. PradeepKumar,** P.S. Rohith, N. Jagannatha. Effects of different radiation on the growth of strontium doped copper tartrate single crystals, ***Applied materials and technology***-2020. ISBN: 978-93-5437-097-7.
5. **K.V. PradeepKumar,** P.S. Rohith, N. Jagannatha, "Studies on Growth and Characterization of Manganese Doped Copper Tartrate Single Crystals at Different Light Radiations", ***AIP Conf. Proc.,*** (In Press).

C. Other publications in journals

1. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar**, "Thermal, optical and electrical susceptibility studies of pure and calcium doped nickel cadmium oxalate crystals", ***Bull. Mater. Sci***. 2021, 44, 185.
2. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar,** M.S. Mangala, K. P. Nagaraja, Delma D'Souza, Growth Kinetics, Spectral Studies of Pure and Mg^{2+} Doped Nickel Cadmium Oxalate Single Crystals, ***Indian J. Pure Appl. Phys.*** 2021, 59, 693.
3. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar,** Effect of Strontium Doping on Thermal and Optical Properties of Gel Grown Copper Cadmium and Cobalt Cadmium Oxalate Crystals, ***Int. J. Chemtech research***, 2020, 13(3) 91-98.
4. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar**, Studies on the growth and characterization of barium doped copper cadmium oxalate single crystals, ***J. Mater. Environ. Sci.,*** 2020, 11(5) 788-794.
5. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar,** Studies on Thermal and Spectroscopic Properties of Magnesium Doped Single Crystal, ***J. Appl. Chem.,*** 2018, 7 (4) 1033-1039.
6. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar,** Effect of Ba^{2+} Incorporation on Thermal and Optical Properties of Cobalt Cadmium Oxalate Single Crystals, ***J. Appl.***

Chem., 2019, 8 (4) 1838-1844.

7. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar,** Optical Properties of Gel Grown Ca^{2+} Doped Copper Cadmium Oxalate Single Crystals, ***Int. J. Phys. Appl. Sci.,*** 2019, 6(8) 01-07.
8. M. S. Mangala, P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar,** Thermal, Optical, and Spectroscopic studies of gel grown Strontium magnesium oxalate crystals, ***Int. J. Chemtech research***, 2021, 14(3), 423-429.

D. Other publications in conference proceedings

1. P. S. Rohith, N. Jagannatha, **K. V. Pradeepkumar,** Growth and Characterization of Pure and Magnesium Doped Copper Cadmium Oxalate Single Crystals, ***Mater. Today: proc.,*** 2019, 8, 85-93.
2. P. S. Rohith, N. Jagannatha**, K.V. Pradeepkumar**, "Dielectric, Magnetic and Spectral studies of gel grown Mg^{2+} doped copper cadmium oxalate single crystals" ***J. Phys. Conf. Ser.,*** 2020, 1495, 012005.
3. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar,** Spectral Studies of Gel Grown $Ca^{2+}$and Mg^{2+} Doped Cobalt Cadmium Oxalate Single Crystals, ***AIP Conf. Proc.,*** 2020, 2220, 060003.
4. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar,** Morphology, Thermal studies of Gel Grown Ca^{2+} and Mg^{2+} Doped Cobalt Cadmium Oxalate Trihydrate Single Crystals, ***AIP Conf. Proc.,*** 2020, 2244, 110013.
5. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar,** Delma D'Souza, Reema K B, Effect of Barium Incorporation on Thermal and Optical Properties of Copper Mixed Cadmium Oxalate Single Crystals, Applied ***Materials and Technology Conference Proceedings,*** 2020, 104, ISBN: 9789354370977
6. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar,** Growth, Thermal and Magnetic Studies of Gel Grown Barium Doped Nickel Cadmium Oxalate Single Crystals, ***AIP Conf. Proc.,*** (In Press).
6. P. S. Rohith, N. Jagannatha, **K.V. Pradeepkumar**, Dielectric and Electrical Polarizability Studies of Gel Grown $Ba^{2+}$and Mg^{2+} Doped Zinc Cadmium Oxalate Crystals, ***AIP Conf. Proc.,*** (In Press).
7. Delma D'souza, N. Jagannatha, K. P. Nagaraja, P. S. Rohith, **K. V. Pradeepkumar,** Growth and Characterization of Divalent Transition Metal Ions Doped Zinc Hydrogen Phosphate Single Crystals, ***AIP Conf. Proc.,*** 2018, 1953, 070023.

2. Paper presented in national/ international conferences

A. Conference attended and presented paper:

1. Presented research paper in International Conference **on "Physics of Materials and**

Nanotechnology (ICPN 2019)" held at Mangalore University, Mangalagangotri on **19-21 Sep 2019.**

2. Presented research paper in International Conference on "**Condensed Matter & Applied Physics [ICC2019]"** held at Govt. Engineering College, Bikaner on **14-15 Oct 2019.**
3. Presented research paper in International Conference on "**Multifunctional Materials" [ICMM-2019]"** held at MRSI and DRDO, Hyderabad on **19-21 Dec 2019.**
4. Presented research paper in International Conference **On "Advances in Materials, Ceramics & Engineering Sciences' (AMCES- 2020)"** held at Dayananda Sagar College of Engineering, Bangalore on **17th -18th Jan 2020.**
5. Presented research paper in International Conference on **"Advanced Materials [SCICON'19]"** held at Amrita Vishwa Vidyapeetham, Coimbatore on **15-17 Dec 2019.**
6. Presented research paper in National Conference on **"Particle Accelerators in Interdisciplinary Research"** held at Mangalore University, Mangalagangotri, on **11-13 April 2017.**
7. Presented research paper in National Conference on **"Condensed matter physics and applications" [CMPA-2018]** held at Manipal Institute of Technology, MAHE, Maniple on **10-11 Sep 2018.**
8. Presented research paper in National Conference on **"Emerging Trends in Material Science"** Held at S. Nijalingappa College,Bangalore on **5th Oct 2018.**
9. Presented research paper in **"National Conference on Recent Advances in Material science"** held FMKMC College, Madikeri on **5th Feb 2019.**
10. Presented research paper in National Conference on **"Advanced Materials for Health, Energy and Environment"** [AMHEE-2019] held at JSS Science and Technology University, Mysuru on **6-7 Sept 2019.**
11. Presented research paper in National Conference on **"Recent Novel Approaches in Chemical Sciences"** held FMKMC College, Madikeri on **12th Feb 2020.**
12. Participated as a delegate in International Conference **on "Materials of Energy and Environment (ICMEE 2018)"** held at Loyola Institute of Frontier Energy (LIFE), Loyola College, Chennai, Tamil Nadu, India, PIN - 600034-**Feb 22-23, 2018.**
13. Participated as a delegate in one day National level seminar **on "current Trends in Chemical research and Development"** [CTCRD-2019] held at Vivekananda College, Puttur on **18th Sept 2019.**
14. Participated as a delegate in one day national level seminar on **"E-Resources, Intellectual Property Rights and Plagiarism-Issues and Challenges"** held at St. Philomena College, Puttur on **29th Sept 2018.**
15. Presented research paper in International Conference on "Nanomaterial's and Their

Applications" held at University of Mysore, Mysore, on **1-2 Mar 2018.**

Mr. Pradeepkumar.K.V. Dr.Jagannatha N.

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Date: